

July 4, 1961

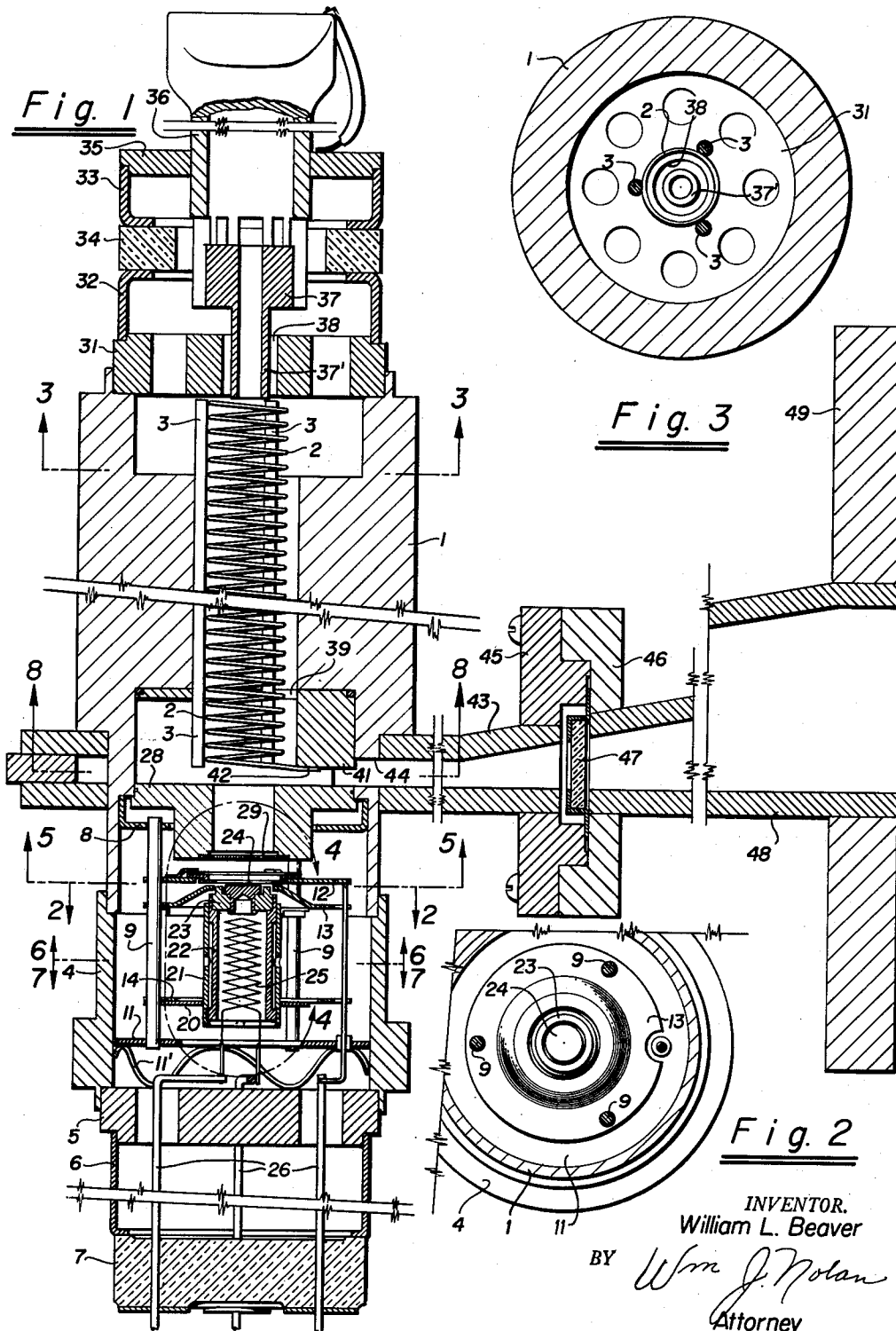
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2,991,391

ELECTRON BEAM DISCHARGE APPARATUS

Filed July 24, 1957

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

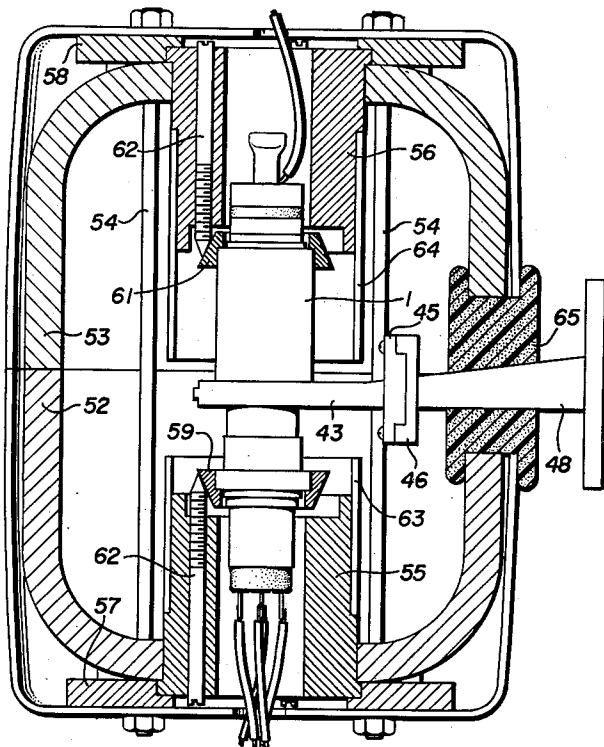


Fig. 9

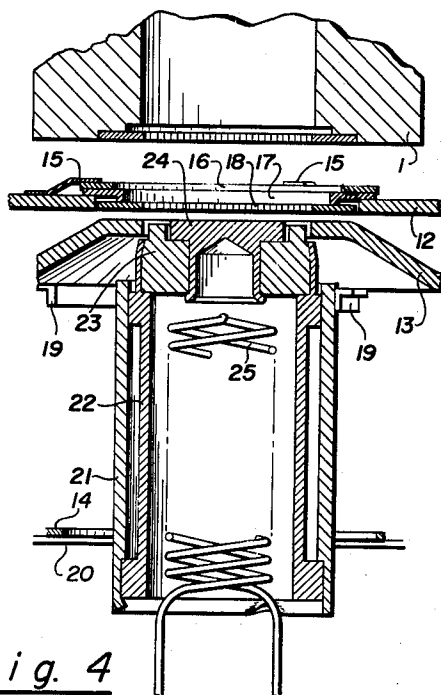


Fig. 4

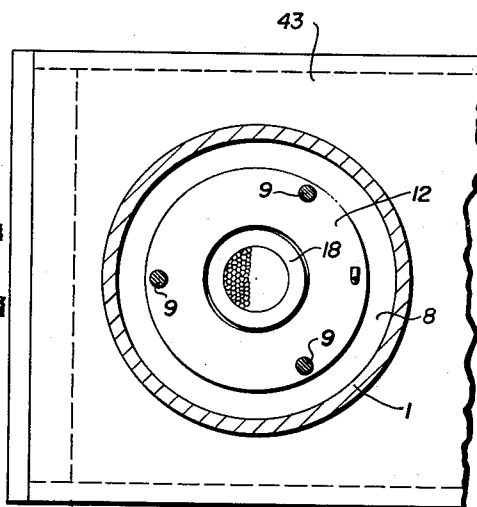


Fig. 5

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Fig. 6

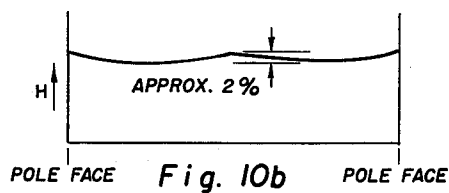
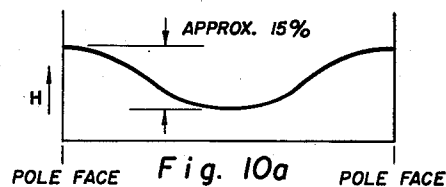
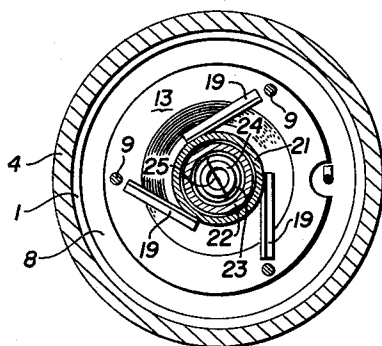


Fig. 7

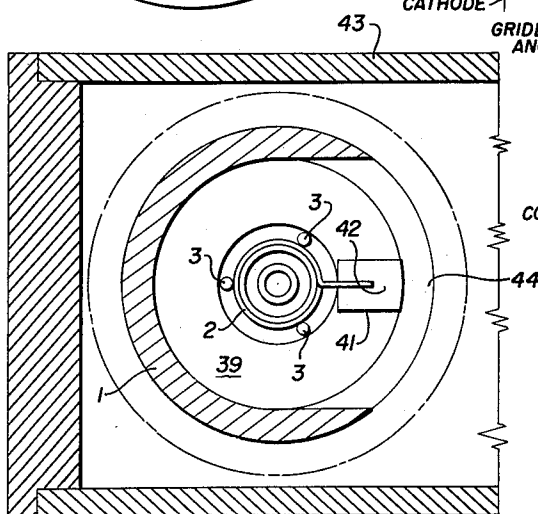
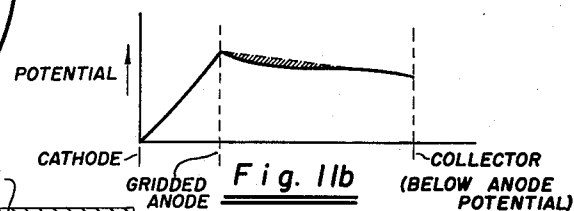
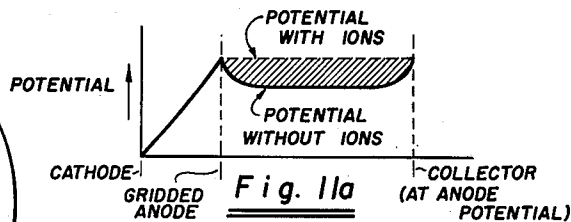
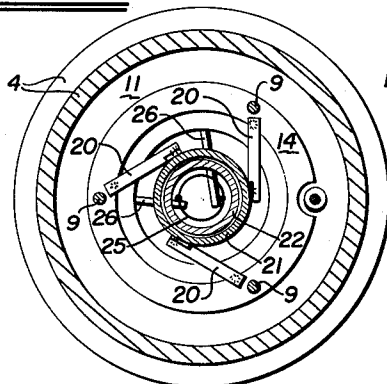


Fig. 8

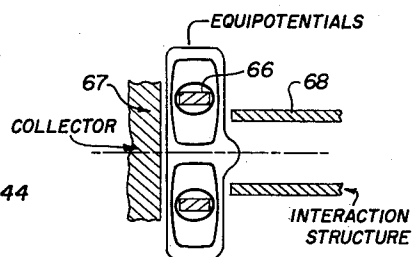


Fig. 12

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2,991,391

ELECTRON BEAM DISCHARGE APPARATUS

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15 Claims. (Cl. 315—3.5)

This invention relates in general to electron beam discharge apparatus and more particularly to a novel device of the traveling wave tube type.

The present invention involves the utilization of novel structural techniques in electron beam discharge devices and finds practical embodiment in a novel backward wave oscillator. The novel features of this invention result in the production of a wide frequency range, voltage tunable backward wave oscillator with excellent frequency stability and low microphonics, the complete backward wave oscillator device being both rugged and relatively light weight.

It is, therefore, the object of the present invention to provide a novel improved electron discharge device incorporating structural features particularly useful in devices having elongated beams and more particularly in devices of the traveling wave type.

One feature of the electron discharge device of the present invention is the provision of a magnetic field forming structure useful in maintaining a magnetically focused electron beam at a constant diameter.

Another feature of the electron discharge device of the present invention is the provision of a novel coupling structure for coupling the slow-wave helix of a traveling wave tube to an input or output waveguide.

Still another feature of the electron discharge device of the present invention is the provision, in an electron discharge device employing an elongated electron beam, of a novel "beam shaver" structure for forming a beam having a controlled circular periphery.

Still another feature of the present invention is the provision of a novel cathode gun and accelerating electrode structure for use in electron discharge devices.

Still another feature of the present invention is the provision of a novel magnetically focused traveling wave tube.

Still another feature of the present invention is the provision of a novel electron discharge device incorporating practical structure for draining ions from the electron beam at the beam collector end of the device.

These and other features and advantages of the present invention will become more apparent upon a perusal of the following specification taken in connection with the accompanying drawings wherein,

FIG. 1 is a longitudinal cross-section view of a backward wave oscillator embodiment of the present invention,

FIG. 2 is a portion of a cross-section view of the backward wave oscillator of FIG. 1 taken along section line 2—2,

FIG. 3 is another cross-section view of the apparatus in FIG. 1 taken along section line 3—3,

FIG. 4 is an enlarged view of a portion of the apparatus shown in FIG. 1 which is encircled by the section lines 4—4 in FIG. 1,

FIG. 5 is a cross-section view of the device of FIG. 1 taken along section line 5—5,

FIGS. 6 and 7 are cross-section views of the backward wave device taken along section lines 6—6 and 7—7, respectively, in FIG. 1 showing the cathode mounting structure,

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FIG. 8 is a cross-section view taken along section line 8—8 in FIG. 1 showing the helix termination structure,

FIG. 9 is a longitudinal cross-section view partly in elevation of the backward wave oscillator device of FIG. 1 mounted in the associated magnetic field producing apparatus utilized for focusing the electron beam in the backward oscillator,

FIGS. 10a and 10b show plots of the magnetic field along the axis of an elongated, magnetically focused electron beam without and with the novel magnetic field shims utilized in the present invention, respectively,

FIGS. 11a and 11b show plots of the potential along the electron beam axis from cathode to collector, FIG. 11a with the collector end at anode potential and FIG. 11b with collector at a potential lower than anode potential, and

FIG. 12 shows a modification of the novel ion collecting structure of this invention.

Referring now to FIGS. 1 to 9 the main body portion of the backward wave oscillator is a cylindrical body 1, as of cuprous nickel, having a multidiameter bore extending longitudinally therethrough, this body in one embodiment being approximately 1½ inches long with a bore diameter of about .2 inch at its smallest diameter. Secured as by a press fit in the central, smaller diameter section of the bore in the main body is a slow wave transmission structure which comprises a conducting tape or wire helix 2 mounted as by glazing within three spaced-apart sapphire rods 3 which form the bearing surface and insulating members between the helix 2 and the main body 1.

The cathode end of this backward wave oscillator comprises a hollow, cylindrical, body-extension member 4 brazed to the lower end of a main body 1 and a disc-shaped iron pole piece member 5 fixedly secured in the lower end of said body extension member 4. A stem cup 6 and vacuum sealing ceramic disc 7 are brazed on this pole piece 5. The cathode gun mounting structure comprises a cage including an end cup 8 which has the ends of the three spaced-apart sapphire insulating and mounting rods 9 fixedly brazed therein, the opposite ends of the rods being brazed in a metallic washer 11.

Three molybdenum annular mounting members or washers 12, 13 and 14, which serve to mount the cathode assembly, are securely affixed on the sapphire rods 9 between the end cup 8 and the mounting washer 11. Secured as by brazing on support washer 12 are three spaced-apart metal tabs 15 which extend over and are brazed to an annular metal retaining washer 16 (see FIG. 4). An annular grid adapter member 17, to which a copper hex beam current control grid 18 is securely affixed as by brazing, is sandwiched between this retaining washer 16 and the support washer 12. Thus this grid 18 is not unmovably affixed to the mounting washer 12 but is mounted thereon in such a way that the grid may expand and contract relative to the support washer 12 with heat changes and the like.

The annular washer 13 is dish-shaped at its central portion and serves as an outer focusing electrode for the beam emitted from the cathode. Three struts 19 of angular cross-section are brazed to the washer 13 and tangentially contact and are brazed to a cylindrical cathode sleeve 21 at three spaced-apart points. Three additional flat struts 20 are brazed to the support washer 14 and are also brazed to the cathode sleeve 21 at equally spaced-apart points. These struts 20 are flat except where they contact the sleeve 21 at which point they have an angular cross-section. This construction provides good temperature expansion characteristics for the cathode. A hollow cylindrical cathode mount 22 having an annular electron emitting cathode button 23 secured in its upper end is securely affixed within the sleeve

21. An internal focusing member 24 is secured within the central portion of said annular cathode button 23. A heater 25 for the cathode extends within the hollow cylindrical member 22.

This above described cathode mounting structure is slipped into the cathode end of the body 1, 4 and held longitudinally positioned under pressure with the circumferential edge of the end cup 8 against the body 1. The pressure is exerted by an annular, sinuous spring 11' (see FIG. 1) bearing against the outer edges of the washer 11 and pole piece member 5.

Four electrical connecting leads 26 extend out from the lower end of the backward wave oscillator through the ceramic seal 7, these four leads serving as electrical connections for the heater 25, the cathode, and the control grid 18. An annular anode and beam shaver member 28 having an elongated bore centrally disposed therein is secured within the main body member 1 and has an accelerating or anode grid 29 secured over the lower end of the bore in spaced-apart relationship from the current control grid 18.

Mounted on the upper end of the main body 1 over the bore therein is an outer internal pole piece 31 as of iron. A pair of metallic cup members 32 and 33 having a ring-shaped insulation member 34 as of ceramic sandwiched therebetween are mounted on the upper surface of the pole piece 31, the upper end of the second cup 33 being sealed closed by an end cap 35. Fixedly secured within the end cap 35 is a pinch-off tube 36 of copper through which this oscillator device is evacuated. The inner end of the pinch-off tube is slotted and has secured therein a hollow cylindrical internal pole piece 37 of iron. This internal pole piece has a reduced-diameter extension 37' which protrudes through a central opening in the outer pole piece 31, there being formed a narrow annular space 38 between the outer pole piece 31 and the inner pole piece 37.

An annular helix-to-waveguide transition member 39 is secured within the body (see FIGS. 1 and 4), this transition member having a raised block portion 41 thereon, the under surface 42 of which is spaced slightly from the opposed surface of the beam shaver member 28. The end of the helix 2 extends out and is fixedly secured as by brazing to this under surface 42. The helix end may be secured in a slot in the transition member 39 if desired. A length of waveguide 43 is coupled through an opening 44 in the main body member 1 to the end of helix 2. A frame member 45 as of cuprous nickel is secured to the outer end of the waveguide 43 and is arranged to be bolted to a matching frame member 46 as of brass, an approximately elliptical ceramic window 47 being sandwiched between the two frame members. An outer waveguide 48 is secured to the outer frame member 46 and extends outwardly to a waveguide flange mounting member 49.

As seen in FIG. 9 this backward wave oscillator device is adapted to be secured within a beam focusing permanent magnet. This magnet comprises the two cup-shaped permanent magnet members 52 and 53 adapted to be secured together by means of bolts 54. Opposed hollow cylindrical pole piece members 55 and 56 are secured in the magnet by means of a pair of pole piece retainers 57 and 58 and the associated bolts 54. Aligning caps 59 and 61 are mounted near opposite ends of the backward wave oscillator tube and are arranged to cooperate with three pointed screws 62 in each pole piece member 55, 56 for aligning the backward wave oscillator in the magnetic field extending between the two pole piece members 55 and 56. Fixedly secured on the pole piece members as by spot welding and extending substantially around the complete backward wave oscillator tube are hollow, cylindrical magnetic field shim members 63 and 64 which are utilized for properly forming the magnetic field lines as will be subsequently explained. The output waveguide 48 extends through an opening in

the side of the magnet member in which a flexible grommet 65 is secured.

The general theory of operation of traveling wave tubes and more specifically of backward oscillators of the type to which this invention relates is well-known to those persons skilled in this art. A very brief recital of this basic operation will be given followed by a more detailed explanation of the theory of operation of certain of the novel features of the present invention.

The annular cathode 23 is heated by means of a current applied to the heater 25 so as to emit electrons which are focused into an annular beam by the focusing members 13 and 24. The density of the beam passing longitudinally through this backward wave oscillating device may be controlled in well-known manner by means of proper potentials applied to the control grid 24. A relatively positive potential on the anode 28 and grid 29 accelerates the electrons in the beam to the desired beam velocity for proper interaction with the helix 2. In traveling along within the helix 2 and adjacent to the turns, the electron beam interacts with a backward traveling wave induced on the helix and delivers up energy to the wave on the helix. This wave energy induced on the helix produces in well-known manner the necessary velocity modulation of the electron beam. The radio frequency wave energy generated on the helix 2 is transmitted over the end 42 of the helix and coupled into the output waveguide section 43 over the transition member 41. In accordance with the theory of backward wave oscillators, the frequency of the device is tunable by varying the anode potential. In one embodiment of this invention, the frequency range was 8.2 to 12.4 kmc., the anode voltage 150 to 600 volts, and the control grid voltage 30 volts. The electron beam is prevented from spreading as it passes along the length of this backward wave oscillator by the application of a longitudinal magnetic field extending axially between the external pole piece members 55 and 56 and internal pole piece members 5 and 31.

This backward wave oscillator device is provided with a novel means for reducing any disturbance of the magnetic field extending along the axial length of the tube. This novel means consists of the two cylindrical magnetic field shim members 63 and 64 which extend in axial surrounding relationship along the length of the tube. In the particular embodiment shown the shim 63 is shorter than shim 64 but in many instances of use it may be desirable to extend shim 63 until such time as the distance between the shims is only sufficient to allow the waveguide portion 43 to extend through the shim members.

There is shown in FIG. 10a a trace of the magnetic field along the axis of this backward wave oscillator between the pole pieces without the field correcting cylinders or shims 63, 64 and in FIG. 10b a trace of the magnetic field along the axis with the field correcting cylinders in place. It will be noticed that without the magnetic shims a variation in the magnetic field as measured in kilogauss along the axis varies by approximately 15% while with the magnetic shims in place the variation has been reduced to only 2%. Without the magnetic field shims, the magnetic field barrels out in the gap between the pole pieces. Such a barreling type field is a divergent magnetic lens which has a deleterious effect on the electron trajectories. The magnetic shims 63, 64 greatly reduce the barreling of the magnetic field between the pole pieces. The shims have the effect of separately producing a curvature of the magnetic field lines which is opposite to the curvature of the initial barreling field in the region of the electron beam. The two fields of opposite curvature can be thought of as adding to produce a nearly constant field as measured along the axis (as shown in FIG. 10b) for certain configurations of magnetic field cylinders. The magnetic field shims or flux correcting elements are uniformly cylindrical in this

embodiment and are used to smooth an initially distorted field but for other pole geometries and other desired field shapes the cross-section of the magnetic field shims may take on other shapes and other positions relative to pole pieces to achieve any desired field shaping effect.

The present embodiment utilizes a permanent magnet and magnetic pole pieces for producing the confining magnetic field but it should be noted that electromagnetic means may be used and these magnetic field shims are also applicable when such focusing solenoids are utilized to provide the magnetic field. Such focusing solenoids in the most desirable cases are continuously wound single solenoids but, of course, in this type of electron device it is necessary to interrupt the windings with a gap wide enough to allow the emergence of the R.F. coupling or output. These two separated solenoid arrangements may also utilize the magnetic field shimming devices or cylinders extending between the gap produced between the two solenoid sections.

This traveling wave tube device also provides a novel arrangement for draining ions from the beam path to the collector end of this device. Ordinarily, when the collector end of the slow wave structure is approximately at the same potential as the anode end, a potential sink or depression is produced in the structure due to electron space charge in the beam. In such a potential depression, ions will collect within the beam until the potential rises to the point where the potential depression between the anode and collector end levels off at which point the ions will escape, the escape of ions due to thermal velocities equalling the ion production rate in the beam. A sketch of this potential distribution is shown in FIG. 11a.

By making the collector negative with respect to the anode, a sloping potential occurs from the anode to the collector end in which case all of the ions will drain toward the collector. A sketch of this potential distribution is shown in FIG. 11b. However, in a magnetically confined or focused beam as in the present case, by making the collector negative to drain ions there is a tendency to cause any secondary electrons produced when the electron beam strikes the collector to flow back into the beam within the helix since this space is more positive than the collector. The presence of these secondary electrons in this beam area further depresses the potential due to the electron space charge and may, in addition, contribute to the excitation of oscillations in the ion cloud. Hence it is desirable to produce a depression in potential near the collector end of the tube for draining ions without permitting the secondary electrons emitted from the collector from passing back into the beam area.

In order to produce this effect the present backward wave oscillator incorporates a novel collector structure. The magnetic pole piece 31 is at anode potential and the non-magnetic center rod 37' is maintained at a negative potential with respect to the anode potential, for example at or very near to cathode potential. Due to this potential distribution, aided by the force exerted on the electrons by the fringing magnetic field, the electron beam current will be collected on the underside and on the bore surface of the pole piece 31. With regard to the secondary electrons emitted from the undersurface of the pole piece member 31, the equipotentials between the pole piece 31, the rod 37' and the end of the helix 2 are shaped such that the secondaries see a potential barrier between the pole piece 31 and the helix 2 and only the very fast secondaries pierce this barrier and enter the helix. With regard to the secondary electrons emitted within the annular space 38, the radial electric and magnetic field in the aperture trap most of the secondaries therein.

The aperture 38 is made as small as possible, consistent with the above functions, so that a minimum of

magnetic field perturbations are produced. The center rod 37' can be made of magnetic material and thus reduce the magnetic field perturbations due to the aperture 38. In such case, the rod 37' must be at or below cathode potential to avoid collecting electrons.

Another collector structure which would accomplish the same result is shown in FIG. 12. A metal ring 66 or other type probe or the like is positioned in front of the collector 67, but out of the beam, and is made negative with respect to the collector and interaction structure or helix 68, for example at cathode potential. This electrode 66 is positioned so that the potential everywhere in the beam is depressed significantly below the potential within the helix 68 and positive ions in the beam can drain radially to the electrode 66. The depressed potential also acts as a secondary electron barrier so that secondaries emitted from the collector 67 are turned back toward the collector. Of course, in all cases the potential barrier must not be so low as to cause primary beam electrons to turn back before reaching the collector.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A helical type traveling wave tube comprising an evacuated main body member, a slow wave helical structure extending longitudinally in said main body member, a cathode gun structure for transmitting an electron beam through said body member in wave energy interaction with said helical member, a wave energy transmission waveguide coupled to an opening in said main body member at one end of said waveguide, the outer end of said waveguide having a wave energy permeable vacuum seal therein, the termination of one end of said helix extending radially out from said helical structure and contacting said body member in the wall of said opening which is nearest to the helical structure whereby electromagnetic coupling is produced between said helical structure and said waveguide through said opening, the termination extending in a direction substantially parallel to the longitudinal direction of the waveguide.

2. A helical type traveling wave tube as claimed in claim 1 wherein said main body member has a longitudinal bore therein through which said helical structure extends, and wherein a helix-to-waveguide transition member is secured in the bore within said main body member near said one end of the helix, a surface on said transition member forming one surface of the opening in said main body member, the termination of said one end of said helix structure extending onto and being electrically coupled to said transition member surface.

3. A traveling wave tube as claimed in claim 2 wherein said helix-to-waveguide transition member comprises an annular member encircling said helix and having a raised portion thereon, the upper surface of said raised portion having the termination of said one end of said helix electrically connected thereto.

4. A traveling wave tube comprising a main body having a slow wave helical structure mounted therein, a cathode gun structure for transmitting an electron beam through said body member in wave-energy interaction with said helical slow wave structure, and an electrode positioned between said cathode gun and said slow wave structure comprising an annular beam shaver member having a bore therein aligned with said cathode, the diameter of said bore in said beam shaver member being slightly less than the outer diameter of the electron beam emitted from said cathode and the inner diameter of the helical structure, the length of said beam shaver member being greater than the diameter thereof whereby said

beam shaver member operates to trim the outermost electrons from the beam emitted from the cathode which would otherwise strike the helix and thereby forms said beam into an even, symmetrical beam having a diameter equal to the diameter of the bore in said beam shaver member and less than the inner diameter of the helical structure.

5. An electron discharge device as claimed in claim 4 wherein said beam shaver member has a grid electrode secured at the cathode end of the bore therein, said member and grid adapted to have an anode potential applied thereto for accelerating said electrons in said beam.

6. An electron beam discharge device of the type wherein the beam is confined from spreading by a magnetic field extending parallel to said beam direction comprising a main body member, a cathode mounted in said main body member and arranged for directing a longitudinal beam through said body member, means for collecting said beam at the end of said body member opposite said cathode, magnetic field producing means coupled to said device for directing a magnetic field longitudinally along said device for confining said electron beam, said magnetic field producing means comprising two cylindrical pole pieces positioned at opposite ends of said main body member, and a pair of hollow cylindrical magnetic shim members mounted at their outer ends on said pole pieces and encircling said main body member and said electron beam, the inner ends of said shims having a gap therebetween for permitting electrical coupling to the main body portion of the beam device, said magnetic shim members acting to shape the magnetic field and prevent magnetic field disturbances in the longitudinal magnetic field whereby proper electron beam focusing is maintained.

7. An electron beam discharge device as claimed in claim 6 wherein said discharge device is a traveling wave tube including a slow wave structure extending longitudinally in said body member for interaction with said electron beam, the shim members encircling a major portion of the length of said slow wave structure.

8. An electron discharge device comprising cathode means for producing an annular-shaped electron beam therein, a substantially hollow structure aligned with said electron beam through which said beam passes and in which positive ions may be formed, said structure adapted to be at an anode potential more positive than the potential of said cathode, an annular-shaped electron beam collector electrode positioned to collect said annular electron beam after transmission through said structure, said electron collector electrode adapted to have a positive potential thereon with respect to said cathode potential such that said beam electrons impinge on said collector, and an ion collecting electrode positioned in axial alignment within the central bore of said annular electron collector and closely spaced from the walls of the bore, said ion collecting electrode adapted to have a negative potential with respect to said electron collector and anode potentials whereby positive ions formed in said structure drain to said ion collecting electrode, the equipotentials formed between the annular electron collector electrode and hollow structure due to said ion collecting electrode potential forming a potential barrier for preventing secondary electrons emitted from said electron collector from entering said structure.

9. An electron discharge device as claimed in claim 8 including magnetic beam focusing means for focusing said beam comprising a pair of pole pieces, one of said pole pieces being positioned behind said cathode and the other of said pole pieces serving as said electron collector electrode.

10. A traveling wave tube comprising a main body member, a cathode adapted to emit a beam of electrons, an elongated helical type slow wave structure in said main body member aligned with said cathode for energy

exchange interaction with said electron beam, an anode and beam shaver member positioned between said cathode and said helix, said member having a bore therein axially aligned with said beam, the diameter of said bore being slightly shorter than both the diameter of the electron beam entering said bore and the inner diameter of said helix, the length of the bore in said member being greater than the diameter thereof, said anode and beam shaver member being adapted to carry a positive potential relative to said cathode for drawing electrons from said cathode, and a wave energy transmission waveguide coupled to an opening in said main body member on the side of said anode furthest from said cathode, the surface of said furthest side of the anode forming a surface extension on the surface of the waveguide nearest the cathode, one end of said helix extending out from said helical structure and contacting said body member in the wall of said opening which is nearest to the helical structure and furthest from said cathode whereby electromagnetic coupling is produced between said helical structure and said waveguide through said opening.

11. A traveling wave tube as claimed in claim 10 wherein said main body member has a longitudinal bore therein through which said helical structure extends, and wherein a helix-to-waveguide transition member is secured in the bore within said main body member near said one end of the helix, a surface on said transition member forming one surface of the opening in said main body member, the end of said helix structure extending onto and being electrically coupled to said transition member surface.

12. A traveling wave tube as claimed in claim 11 including magnetic field producing means coupled to said device for directing a magnetic field longitudinally along said device for confining said electron beam, said magnetic field producing means comprising two cylindrical pole pieces positioned at opposite ends of said main body member, and a pair of hollow cylindrical magnetic shim members mounted at their outer ends on said pole pieces and encircling said main body member and said electron beam, said magnetic shim members acting to prevent magnetic field disturbances in the longitudinal magnetic field whereby electron beam focusing is maintained.

13. A helical type traveling wave tube comprising a main body member, a slow wave helical structure extending longitudinally in said main body member, a cathode gun structure for transmitting an electron beam through said body member in wave energy interaction with said helical member, a wave energy transmission waveguide coupled to an opening in said main body member, said opening and said waveguide forming a wave energy path coupled to one end of said helix, the walls of said opening forming a smooth helix-to-waveguide transition, the waveguide and opening tapering smoothly down to the impedance of the helix, one end of said helix extending radially out from said helical structure and contacting the wall of said opening which is nearest to the helical structure whereby electromagnetic coupling is produced between said helical structure and said waveguide through said opening, the said one end of said helix extending in a direction substantially parallel to the longitudinal direction of the waveguide.

14. A helical type traveling wave tube as claimed in claim 13 including a helix-to-waveguide transition member secured on said main body near said one end of the helix, a surface on said transition member forming one surface of the opening in said main body member, the end of said helix structure being electrically coupled to said transition member surface.

15. An electron beam discharge device of the type wherein the beam is confined and prevented from spreading by a magnetic field extending parallel to said beam direction comprising a cathode for directing a longitudinal beam in the device, an interaction circuit for inter-

acting with the beam and means along the path of said beam for collecting said beam after its passage through the beam interaction circuit of the electron discharge device, and magnetic field producing means for directing a magnetic field longitudinally along the beam path for confining said electron beam, said magnetic field producing means comprising two pole pieces positioned at opposite ends of the beam path, said opposed pole pieces each having a hollow, cylindrical magnetic shim extension encircling the beam path, the shims extending toward each other from their respective pole pieces, said magnetic shims having their inner ends spaced apart to form a gap therebetween for permitting electrical coupling to the interaction circuit of said electron beam device, said magnetic shims acting to shape the magnetic field and prevent magnetic field disturbances in the confining magnetic field whereby proper electron beam focusing is maintained.

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